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Assessing the suitability of stream water for five different uses and its aquatic environment

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Abstract Surface water is one of the essential resources for supporting sustainable development. The suitability of such water for a given use depends both on the available quantity and tolerable quality. Temporary status for a surface water quality has been identified extensively. Still the suitability of the water for different purposes needs to be verified. This study proposes a water quality evaluation system to assess the aptitude of the Selangor River water for aquatic biota, drinking water production, leisure and aquatic sport, irrigation use, livestock watering, and aquaculture use. Aptitude of the water has been classified in many parts of the river segment as unsuitable for aquatic biota, drinking water production, leisure and aquatic sport as well as aquaculture use. The water quality aptitude classes of the stream water for nine locations along the river are evaluated to contribute to decision support system. The suitability of the water for five different uses and its aquatic ecosystem are verified.

Keywords Aggregation method · Stream water · Water quality aptitude · Water quality evaluation system · Water use

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Introduction

A synergic management of water quantity and quality in the future is an important issue and needs to be promoted for supporting sustainable development. Population growth and socioeconomic development are currently driving a rapid increase in water demand, especially from agricultural, industrial, and household sectors. Looking forward, agricultural and industrial productivity needs to continue to increase and will require more water to meet the demands of growing populations. This, coupled with spatial and temporal variations in water availability (Lim and Surbeck 2011), means that the water to produce food for human consumption, industrial processes, and all other uses is becoming scarce and affects the environmental pressure in a river basin. The reduction in river water quality is a clear indicator of the decline in the environmental health of a river basin. River water quality mostly depends on the quantity of dropped pollutants originating from household, municipality, industry, aquaculture, agriculture, livestock as well as sand mining, and on the purifying capacity of the river. The river water quality has deteriorated by major water quality parameters like dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), turbidity, nitrate (NO_3^-), coliforms, and certain heavy metals level. The unique feature of water is proved by the fact that the use of the available water in a river depends on the suitable aptitude and is different for each purpose. One way to rank environmental aspects is to use water aptitude classes representing a range of most suitable to unsuitable. There is a need to verify the aptitude of the available water to ensure its suitability for multipurpose (Fulazzaky and Sutardi 2008). Because of the deterioration of water quality reduces the usability of the resources for multistakeholder (Fulazzaky et al. 2010), the quality of surface water has become a critical issue in many countries especially due to the concern that freshwater will be a scarce resource in the future. Hence, water quality monitoring is required to assess whether the various water aptitudes are effective in attaining the goals of different water allocation (Pesce and Wunderlin 2000). Water is one of the most vital natural resources for all life on Earth. The use of water depends on the quality and quantity of the available waters, and the users can choose from among many different efficiency practices. It is a need therefore to foster integrated water resources management (IWRM) for each river basin. This concept formulates hydrological river basin boundary approach that considers all the interests of multistakeholder to highly appreciate the socioeconomic concern of the people for the entire river basin.

Many countries adopt a water quality standard for maintenance of surface water source, such as in National Water Quality Standards for Malaysia (NWQSM), United States Environmental Protection Agency (US EPA) Clean Water Act, and European Commission on Water Framework Directive (EC WFD). Many water quality criteria set a maximum level for the concentration of a substance in water which will not be harmful when the water is used continuously for multipurpose. The overall aim of the NWQSM, US EPA Clean Water Act, and EC WFD is to establish a framework for the protection and management of surface waters including ensuring the tolerable quality of raw water for drinking water production. Using six water quality index (WQI) parameters (i.e., DO, BOD, COD, SS, NH_4^+, and pH) the Malaysia's Department of Environment (MDOE) promotes as a tool to classify the status of surface water quality (DOE 2003; Sari and Wan Omar 2008; Shuhaimi-Othman et al. 2007). The six parameters defined in the MDOE-WQI, but not satisfactorily defined the water quality status in this part, will not have the meaning given in the assessment since many other water quality parameters have to be identified for environmental monitoring. For example, a major contribution of the phosphorus matter leads to degradation of inland water quality through algal blooming and associated eutrophication (Hoorman et al. 2008). Still a comprehensive assessment of the water qualities to respond the user needs set in the national water quality assessment guideline is important (Ning and Chang 2002). A newly comprehensive tool is necessary to propose for the assessment of river water quality. The proposed tool helps to identify together the quality status and aptitude of the available water. For example, this study uses the water quality evaluation system (WQES) to assess the aptitude of the Selangor River water for five different uses and its aquatic environment, due to the role of such stream water as very important for supporting sustainable development in the region of the study. The application of WQES has been proposed partly for the classification of WQI to define water quality status for the Selangor River (Fulazzaky et al. 2010). In addition, the system has been proposed for the classification of both WQI and water quality aptitude (WQA) to define water quality status and suitability of water for different uses, respectively, at Brantas and Citarum Rivers (Fulazzaky 2009; Fulazzaky 2010).

The objectives of this study are (1) to cluster the aptitudes of steam water along the Selangor River based on the WQA classes, (2) to analyze the WQA classes for the assessment of the suitability of the river water for five different uses and its aquatic ecosystem, and (3) to investigate the significance of the study to be promoted as decision support system (DSS) for water users in allocating their water wisely and for decision makers in managing water resources.

Methodology

General description on the WQES

Global river quality-based assessment (Fig. 1) of three commonly performed manageable evaluation procedures can be proposed for a river quality assessment system. As consequence of using this approach, there are three types of choice, such that: (1) water choice (referred as WQES) to assess physicochemical and biological quality of water in terms of the WQI and suitability of water for supporting natural functions of aquatic environment and water uses in terms of the WQA; (2) physical structures choice as physical quality evaluation system to assess level of manmade change on main channel, channel margins, and river banks; and (3) biological choice as biological quality evaluation system to assess state of biosciences of

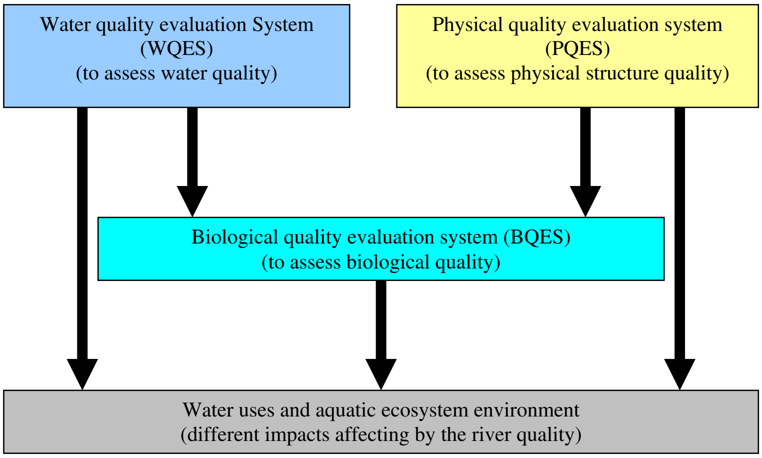

Fig. 1 Global quality assessment for a river

aquatic environment (Oudin et al. 1999; Fulazzaky and Hadimuljono 2010). The qualities of water and physical structure of a river influence to the quality of aquatic ecosystem. Still a strong exertion of their perspective rights over the IWRM for the entire river basin is necessary to be addressed for supporting sustainable development.

The WQES is one of the evaluation methods and intends to transform large quantities of the water quality data into a single number of the information. This aggregation method possesses the operational procedure standard converting the complicated data to a valid letter of the information and may be applicable for all monitored water quality parameters. The use of the WQES is flexible and may consider all the monitored parameters rather than many current systems used by the governmental organizations in different countries are only binding to the fixed water quality parameters. As information, the outcomes of the evaluation of a water quality can be grouped into two types of cluster analysis, i.e., (1) water quality status and (2) water suitability for five different uses and its aquatic ecosystem, as shown in Fig. 2. The risk- based approach will enhance the ability to focus on identifying and controlling critical water quality parameters that affect the contamination of stream water and river productivity (Fulazzaky 2009; Fulazzaky 2010; Fulazzaky et al. 2010). The WQES is based on the notion of indicators of modification from natural conditions. Parameters of similar nature and impact on environment as shown in Table 1 are grouped into 15 alterations of indicators of water quality. The WQES promotes a tool that offers the possibility to record and synchronize all the water quality monitoring data expressed by the different parameters to transform into a simple number of information clustering either in terms of WQI or in terms of WQA. The assessment of using this particular analysis based on the thresholds basis was chosen due to a greater exploratory objective in information collection, a better approach of the procedural assessment defined in a

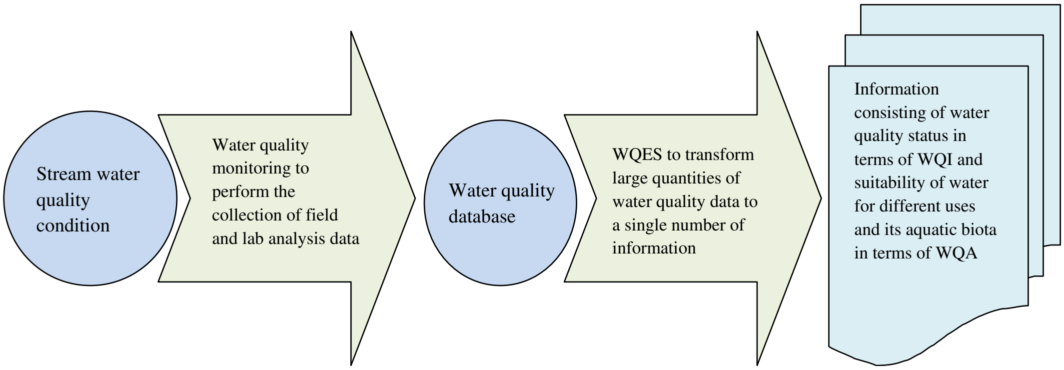

Fig. 2 Link of the stream water quality condition to a single number of the information

Table 1 Alteration with its water quality parameters

No	Alteration	Parameters
1	Oxidized organic matter	DO, $\%O_2$, COD, PV, BOD, DOC, NKJ, NH_4^+
2	Nitrogen matter	NH_4^+, NKJ, NO_2^-
3	Nitrates	NO_3^-
4	Phosphorus matter	PO_4^{3+}, P-total
5	Suspended particles	SS, turbidity, transparency
6	Color	Color
7	Temperature	Temperature
8	Mineralization	Conductivity, salinity, hardness, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, K^+, Na^+, TAC, hardness
9	Acidification	pH, dissolved Al
10	Microorganisms	Total coliforms, fecal coliforms, fecal streptococci
11	Phytoplankton	ΔO_2, ΔpH, $\%O_2$, and pH, chlorophyl a+pheopigments, algae
12	Mineral micropollutants in raw water	As, Hg, Cd, Cr-total, Pb, Zn, Cu, Ni, Se, Ba, CN
13	Metals in bryophytes	As, Hg, Cd, Cr-total, Pb, Zn, Cu, Ni
14	Pesticides in raw water	List of pesticides (see Oudin et al. 1999)
15	Organic micropollutants non-pesticides in raw water	List of organic micropollutants non-pesticides (see Oudin et al. 1999)

Sources: Oudin et al. 1999

modular way, and more accurate information resulting from more parameters analysis adaptable to scientific and technical development as well as regional peculiarities. What advantages might a tool have in responding to the needs of the policy makers, engineers, scientists, and people applied to the entire river basin. The origins of the thresholds coming from certain regulations of such as European Directives, French Decrees, WHO Recommendations, US EPA Regulation, and Canadian Decrees relate to the quality of stream water for different uses were considered in evaluating the suitability of the water.

In a previous study by Fulazzaky et al. (2010), the use of WQES to cluster the WQI for the assessment of the water quality status has been proposed. Thus, in this study focuses on the evaluation of the WQA classes to assess the suitability of the Selangor River water for five different uses and its aquatic ecosystem. Even to apply basis that the use of 243 measurement results original from 27 water quality parameters permits to cluster the WQA classes along the Selangor River, more accurate information may help explain the aptitude of the water when the evaluation considers large quantities of water quality measurement results and parameters at the same time during a study. In addition to the sampling points (see Fig. 3) that were used to estimate water suitability at the Selangor River, monitoring for water quality was conducted at nine locations. Most human activities in the basin affect water quality, directly through discharge of sewage and other wastewater or indirectly through land-use changes. In order to improve water quality, it is important to assess the contribution from all the main sources. This is not easy as there are insufficient data and some contributions are difficult to estimate. Since 2000, the MDOE has used nine stations in the Selangor River where water samples monitor regularly. The sampling programs were reviewed in 2005 and 11 additional stations were added to its tributaries, bringing the total to 20 stations. Based on the water monitoring results for each water quality parameter, the use of appropriate thresholds was able to classify the WQA criteria at nine locations of the river segment. These criteria define the suitability of the stream water for drinking water production, leisure and aquatic sport, irrigation, livestock watering, aquaculture as well as its aquatic biota.

WQA classification for the different purposes

The decision-making process of using the WQES is the study of identifying and defining WQA for five different uses and its aquatic environment based on the

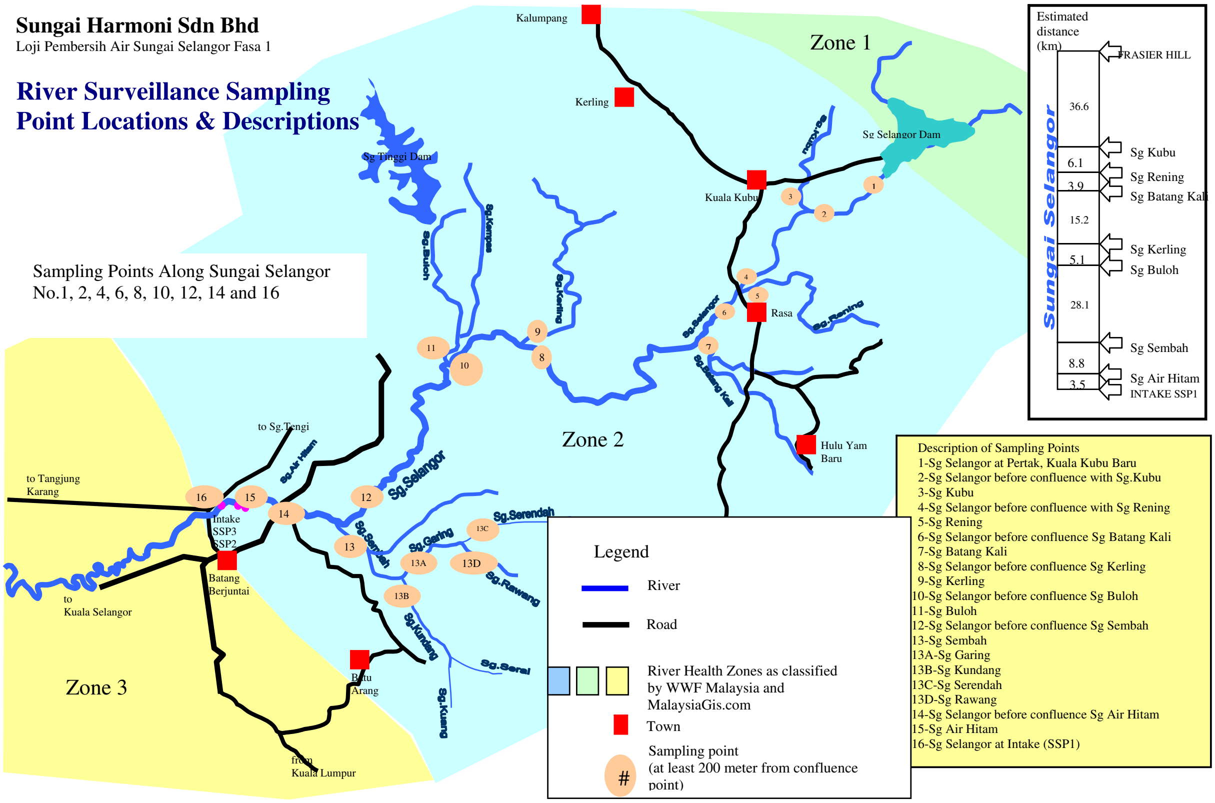

Fig. 3 Sampling stations along the Selangor River

worst value of the water quality parameter(s). This decision-making process differs from the traditional decision-making processes. For example, the analytical hierarchy process is a structured technique for dealing with complex decisions (Aly and Vrana 2008), and the fuzzy decision making in such a setting is defined as the simultaneous satisfaction of the constraints and the goals (Kaymak and Sousa 2003). Defining the thresholds for each parameter (Table 1) are grouped into five classes with respective colors of blue, green, yellow, orange, and red to express the most suitable aptitude for unpolluted water and good aptitude, moderate aptitude, bad aptitude, and very bad aptitude for very polluted water, respectively, except the thresholds grouped into three classes with respective colors of blue, yellow, and red to express the most suitable aptitude, moderate aptitude, and very bad aptitude of the water, respectively, as shown in Fig. 4. The five classes are different from the three classes because of the relevant explanatory variables are different for suitability analysis of the different water uses. Different uses raise different concerns and therefore different standards of thresholds are considered. A flowchart (Fig. 5) of the WQA assessment for five different uses and its aquatic ecosystem consists of: (1) five WQA classes for the assessment of the suitable water for aquatic biota. They indicate a gradual impoverishment of the biological structure, including the disappearance of the taxa most sensitive to pollution. For example, Table 2 gives the thresholds of phosphorus matter alteration. This study evaluated seven alterations of using 15 parameters (i.e., DO, $\%O_2$, COD, BOD, NH_4^+, NO_3^-, turbidity, pH, As, Hg, Cd, Pb, Zn, Cu, and CN) to assess the WQA classes of the Selangor River water for supporting its aquatic environment; (2) five WQA classes for the assessment of the suitable water for drinking water production. Given in Table 2 is an example of suspended particles alteration having five column thresholds that can classify the WQA. This study evaluated eight alterations of using 22 parameters (i.e., DO, $\%O_2$, COD, BOD, NH_4^+, NO_3^-, turbidity, conductivity, Cl^-, SO_4^{2-}, Mg^{2+}, Na^+, pH, total coliforms, fecal coliforms, As, Hg, Cd, Pb, Zn, Cu, and CN) to assess the WQA classes of the stream water for

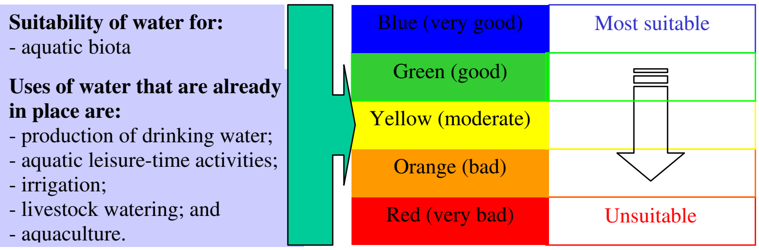

Fig. 4 Classification of water suitability for different uses and aquatic biota

drinking water production; (3) three WQA classes graded the thresholds for the assessment of the suitable water for recreation and aquatic sport. Table 3 shows the example of the thresholds for microorganism alteration. This study evaluated two alterations of using three parameters (i.e., turbidity, total coliforms, and fecal coliforms) to assess the WQA classes of the river water for leisure and aquatic sport; (4) five WQA classes for the assessment of the suitable water for irrigation. As example, the thresholds for mineralization alteration are presented in Table 2. This study evaluated three alterations of using eight parameters (i.e., Cl^-, total coliforms, fecal coliforms, As, Cd, Pb, Cu, and Zn) to assess the WQA classes of the stream water for irrigation use; (5) three WQA classes for the assessment of the suitable water for livestock watering. It is one example of the thresholds that is for nitrates alteration as shown in Table 3. This study evaluated three alterations of using nine parameters (i.e., NO_3^-, SO_4^{2-}, Na^+, As, Hg, Cd, Pb, Zn, and Cu) to assess the WQA classes of the river water for livestock watering; and (6) three WQA classes for the assessment of the suitable water for aquaculture use. Table 3 presents an example of the thresholds for oxidized organic matters alteration. This study evaluated six alterations of using 10 parameters (i.e., DO, BOD, NH_4^+, NO_3^-, pH, Hg, Pb, Zn, Cu, and CN) to assess the WQA classes of the water for aquaculture use.

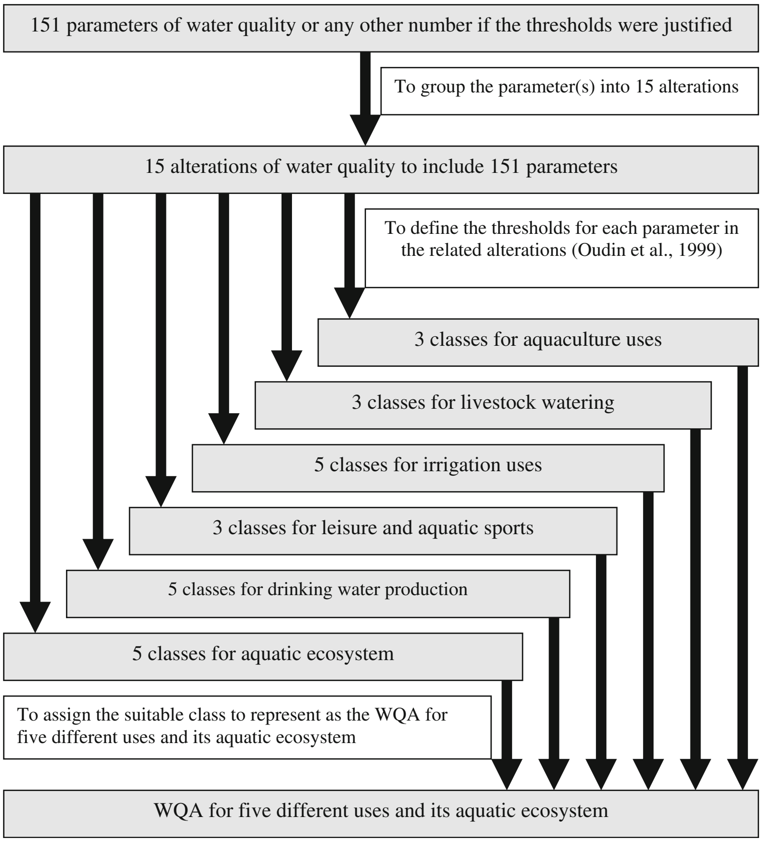

Fig. 5 Flowchart of the WQA assessment for different purposes

Table 2 Examples of the thresholds grouped into five WQA classes

Parameter	WQA class				
	Blue	Green	Yellow	Orange	Red
Phosphorus matter alteration for assessing the suitable water for aquatic ecosystem					
Total phosphorus (mg/l P)	0.05	0.2	0.5	1	
PO_4^{3-} (mg/l PO_4)	0.1	0.5	1	2	
Suspended particles alteration for assessing the suitable water for drinking water production					
SS (mg/l)	5	50	2,000	5,000	
Turbidity (NTU)	2	35	1,500	3,750	
Transparency (m)	2	1	0.1	0.05	
Mineralization alteration for assessing the suitable water for irrigation					
Salinity (mg/l)	500	1,500	2,500	3,500	
Chlorides[a] (mg/l)	180	360	700		

Sources: Oudin et al. (1999)

[a] Chlorides to classify into four classes

Results and discussions

Analysis of the water suitability for aquatic biota

Spatial and temporal changes in water quality for a river basin are due to population growth and economic development. Consequently, the quality of the surface water varies from the time to time and needs to be monitored periodically under authority of the local government. For example, the results of monitoring water quality of the Selangor River have declined gradually during the 7-year period from 2000 to 2006. The difference in projections suggests that the deterioration of water quality increases for the years: 2008, 2009, 2010, 1011, and in the future (DID 2007). It has been postulated that the high pollution in river water caused the problems of biodiversity depletion. The water quality monitoring may take several locations along the river and is required to assess the aptitude of water for its aquatic biota. The earlier study by Castela et al. (2008) supports the need for incorporating functional measures in evaluations of stream ecological integrity. The effects on zooplankton were caused by changes in habitat structure due to the

Table 3 Examples of the thresholds grouped into three WQA classes

Parameter	WQA class		
	Blue	Yellow	Red
Microorganisms alteration for assessing the suitable water for leisure and aquatic sport			
Escherichia or therm coliforms[a] (U/100 ml)	100	2,000	
Fecal streptococci or enterococci (U/100 ml)	100	400	
Total coliforms (U/100 ml)	500	10,000	
Nitrates alteration for assessing the suitability of water for livestock watering			
NO_3^- (mg/l NO_3)	50	450	
Oxidized organic matter alteration for assessing the suitable water for aquaculture uses			
Dissolved O_2 (mg/l O_2)	7	5	
BOD (mg/l O_2)	5	10	

Source: Oudin et al. (1999)

[a] Assimilable *Escherichia coli*

strong decline of macrophytes. Slow degradation of metazachlor combined with the absence of recovery in both chlorophytes and macrophytes is likely to cause long-lasting effects on aquatic ecosystems (Mohr et al. 2008). Due to analysis of the multifarious effects of pollution on aquatic organisms by which declaring risks separate from each other is difficult, the use of WQES can be simplified by making a reasonable assumption in terms of the WQA class which ranges from the most suitable to unsuitable water for aquatic biota (Fulazzaky 2009; Fulazzaky 2010).

Aggregate analysis of seven alterations of the water quality data for the Selangor River justifies that: (1) moderately suitable water for aquatic biota can be related to the alterations of oxidized organic matter, nitrogen matter, nitrates, acidification, and phytoplankton causing the aptitude of water differs from the excellent suitability to good suitability and to moderately suitable water judging the WQA classes of blue, green, and yellow, respectively, were verified; (2) aptitude of the water upstream the station 02 has good suitability for aquatic biota judging the WQA class is green even if a slight water depletion from the most suitability to goodly suitable water can be related to the alterations of oxidized organic matter, nitrates, and acidification; (3) aptitude of the river water related to suspended particles alteration terribly declines from the most suitability upstream the station 02 to bad suitability in middle parts of the river segment (stations 04 and 06) and to unsuitable water aptitude for aquatic biota downstream the station 08, judging the WQA classes of blue, orange, and red, respectively, were verified; and (4) aptitude of the water related to mineral micropollutants alteration declines moderately from the most suitability upstream the station 06 to moderate suitability in the middle parts of the river segment (stations 08, 10, and 12) and to badly suitable water for aquatic biota downstream the station 14, judging the WQA classes of blue, yellow, and orange, respectively, were verified (see Table 4). This study finds that both the conditions of bad and very bad water aptitude for aquatic biota along the river are dependent on the excessive suspended particles in water. Very bad aptitude of the water downstream the station 08 indicates the water capability of considerably reducing the number of sensitive taxa or eliminating them, with a very low diversity. The water aptitude in the middle river segment (stations 04 and 06) is not suitable for aquatic biota indicating water capability of considerably reducing the number of sensitive taxa, with reduced diversity. A good suitability of water for aquatic biota upstream the station 02 indicates water capability of probably causing only the disappearance of certain sensitive taxa, with adequate diversity.

The circumstances of bad to very bad aptitude of the stream water for aquatic environment are due to the alterations of suspended particles downstream the station 04 and mineral micropollutants downstream the station 14 are evident. The potential pollutants that originate from municipalities, poultry farms, sand mining, and industrial estates are expected. This is partly due to the improved sensitivity of the water is dependent on the suspended particles hence the main object of the recommended treatment units is to reduce the solid contents from the sewage of the related activities and to remove all the excessive suspended particulates.

Analysis of the water suitability for drinking water production

Importance of using the WQES to assess the suitability of the stream water for drinking water production is to cluster the WQA along the river. This helps identify and ensure proper operation of all aspects of a water treatment technology in accordance with the WQA and avoids the risks based on the decision made for selecting the functions of the water treatment plant facilities. The observed risk analysis and risk-based decision-making practices are discussed, together with their maturity of implementation. A deeper understanding of the practical and theoretical underpinnings of risk management can be made between organizational capabilities in the essential water business process (MacGillivray and Pollard 2008). This preventive feature thus lies at the core of risk management for the provision of safe drinking water (Hrudey et al. 2006). In case of the technical problems, fluctuation of turbidity in raw water makes it difficult to adjust alum dose, resulting in treated water quality unstable, and handling of sludge disposal difficult (Sthiannopkao et al. 2007). The evaluation of using eight alterations to assess the suitability of the Selangor River water for drinking water production justifies that: (1) aptitude of the stream water related to nitrates, suspended particles, mineralization, acidification, phytoplankton, and mineral micropollutants alteration ranges from

Table 4 Results of the WQA classes for the Selangor River water

Alteration	Results of WQA analysis								
	01	02	04	06	08	10	12	14	16
WQA for biological potentiality function	g	g	o	o	r	r	r	r	r
Oxidized organic matter	g	g	g	g	y	y	y	y	g
Nitrogen matter	b	b	b	g	y	y	y	y	y
Nitrates	g	g	g	g	g	g	y	g	g
Phosphorous matter			No data available						
Suspended particles	b	b	o	o	r	r	r	r	r
Temperature			No data available						
Asidification	b	g	y	b	b	b	b	b	b
Phytoplankton	b	b	b	b	b	b	b	b	b
Mineral micropollutants in raw water	b	b	b	b	y	y	y	o	o
Metals in bryophytes			No data available						
Pesticides in raw water			No data available						
Organic micropollutants non-pesticides in raw water			No data available						
WQA for drinking water production	y	o	o	r	r	r	r	r	r
Oxidized organic matter	b	b	b	b	o	o	y	y	y
Nitrates	b	b	b	b	b	b	b	b	b
Suspended particles	g	g	y	y	y	y	y	y	y
Color			No data available						
Mineralization	b	b	b	b	b	b	b	b	b
Asidification	b	b	b	b	b	b	b	b	b
Microorganisms	y	o	o	r	r	r	r	r	r
Phytoplankton	b	b	b	b	b	b	b	b	b
Mineral micropollutants in raw water	b	b	b	b	y	y	y	y	y
Pesticides in raw water			No data available						
Organic micropollutants non-pesticides in raw water			No data available						
WQA for leisure and aquatic sport	y	r	r	r	r	r	r	r	r
Suspended particles	b	b	r	r	r	r	r	r	r
Microorganisms	y	r	r	r	r	r	r	r	r
WQA for irrigation use	g	g	g	g	g	g	g	g	g
Mineralization	b	b	b	b	b	b	b	b	b
Microorganisms	g	g	g	g	g	g	g	g	g
Mineral micropollutants in raw water	b	b	b	b	b	b	b	b	b
Pesticides in raw water			No data available						
WQA for livestock watering	b	b	b	b	b	b	b	y	b
Nitrogen matter									
Nitrates	b	b	b	b	b	b	b	b	b
Mineralization	b	b	b	b	b	b	b	b	b
Mineral micropollutants in raw water	b	b	b	b	b	b	b	y	b
Pesticides in raw water			No data available						
WQA for aquaculture use	b	b	y	y	r	r	r	r	r
Oxidized organic matter	b	b	b	b	r	r	y	y	y
Nitrogen matter			No data available						
Nitrates	b	b	b	b	b	b	y	b	b

Table 4 (continued)

Alteration	Results of WQA analysis								
	01	02	04	06	08	10	12	14	16
Phosphorous matter			No data available						
Suspended particles	b	b	y	y	r	r	r	r	r
Mineralization	b	b	b	b	b	b	b	b	b
Asidification	b	b	b	b	b	b	b	b	b
Phytoplankton			No data available						
Mineral micropollutants in raw water	b	b	b	b	r	r	r	r	r
Number of parameter analysis	27	27	27	27	27	27	27	27	27

01 Pertak Kuala Kubu Baru, *02* Selangor River before confluence with Kubu River, *04* Selangor River before confluence with Rening River, *06* Selangor River before confluence with Batang Kali River, *08* Selangor River before confluence with Kerling River, *10* Selangor River before confluence with Buloh River, *12* Selangor River before confluence with Sembah River, *14* Selangor River before confluence with Air Hitam River, *16* Selangor River at intake of the sungai Selangor phase 1 (SSP1), *b* blue, *g* green, *y* yellow, *o* orange, *r* red

the most suitability to good suitability and to moderately suitable water judging the WQA classes of blue, green, and yellow, respectively, were verified; (2) aptitude of the river water is dependent on the microorganisms overdose due to the worst quality along the river relates to microorganisms alteration; (3) aptitude of the water declines terribly from the moderate suitability upstream the station 01 to bad suitability in the middle river segment (stations 02 and 04) and to unsuitable water for drinking water production downstream the station 06 judging the WQA classes of yellow, orange, and red, respectively, were verified; and (4) bad aptitude of the water in the middle river segment (stations 08 and 10) related to oxidized organic matter alteration was verified judging the WQA class is orange (see Table 4). The quality of the stream water related to organic matter improves from orange in the middle river segment (stations 08 and 10) to yellow WQA class downstream the station 12 there is due to the oxygen replenished from atmosphere and photosynthesis accelerates self-purification in water.

This study finds that moderate, bad, and very bad water aptitude for drinking water production along the river relates to microorganisms alteration. Accordingly, a moderate aptitude of the water upstream the station 01 is feasible to be treated using a conventional technology (i.e., chemical and physical treatment and disinfection) to ensure proper drinking water production. Still a bad water aptitude in the middle river segment (stations 02 and 04) is possible to be treated for drinking water production hence using an advanced technology is recommended. A very bad aptitude of the river water downstream the station 06 is unsuitable to be treated for drinking water production due to the treatment of such stream water will be snared to a high investment and operational cost in view of the balanced prices of the water delivery to consumers.

Circumstances of bad and very bad water aptitude for drinking water production are dependent on the alterations of microorganisms downstream the station 02 and oxidized organic matter in the middle river segment (stations 08 and 10). The Selangor River has a number of poultry farms along its banks, and these are potential sources of pollution. Domestic waste discharge from the villages and towns in the entire river basin is also an important source of pollution. The results of this study will improve our understanding of the pollutant loads from poultry farms and municipalities caused deterioration of water quality. Such a program would be easy to be implemented a proper wastewater treatment plant (WWTP) to reduce some amount of pollutants discharging the river. Even if a moderate suitability of the stream water was achieved, a conventional technology may be recommended in treating the water for drinking water production.

Analysis of the water suitability for leisure and aquatic sport

It is forbidden to use the Selangor River water for leisure and aquatic sport except the waters upstream the station 01 due to both the excessive amounts of microorganisms and suspended particles verified. Experimental data validation shows that the WQA classes along the river are red (see Table 4). A moderate water aptitude upstream the station 01 relates to the absence of poultry farms in the upper part of the river banks (DID 2007). This study finds that very bad aptitude of the river water for leisure and aquatic sport was satisfied by both the alterations of suspended particles and microorganisms. The potential sources of the pollutant loads from poultry farms, domestic wastewater, and sand mining are expected. There is one thing that it needs to reduce some amounts of suspended particles and microorganisms while having a suitable water aptitude for leisure and aquatic sport is essential for the region.

Analysis of the water suitability for irrigation use

In view of the water aptitude for irrigation use this study finds that the available water along the river has good suitability, judging the WQA classes of green verified (see Table 4). The Selangor River water is still recommended to be used for all the irrigated lands including the most sensitive and neutral or alkaline soils, together with crops ranging from the sensitive plants to very hardy plants. A good aptitude of the water associated with the amount of microorganisms was verified there due to both the concentrations of minerals and mineral micropollutants in the water are classified as most suitability for irrigation use. The Selangor River water use has reportedly been allocated for 20,000 ha of agricultural lands at Tanjong Karang major irrigation scheme and 2,238 ha of paddy fields of 17 locations of minor irrigation scheme at Hulu Langat and Hulu Selangor (DID 2007). Unfortunately, overflow of the irrigated water is usually to drain back into the river. The runoff from paddy field as verified in the Ile de Camargue, France, carries important loads of dissolved pesticides to the wetlands including the river (Comoretto et al. 2008). In a previous study by Nikolaidis et al. (2008), it was reported that drinking water pollution in the Evros region Northern Greece can be attributed to excessive fertilizer use from agricultural land sources.

Analysis of the water suitability for livestock watering

Although not all of the water along the Selangor River is excellently suitable for livestock watering, the use of the river water is acceptable for watering of breeding animals of: (1) young animals that are very sensitive to all pollutants, (2) animals of mature age that are less vulnerable, and (3) animals for reproduction. A moderate water aptitude (see station 14) for livestock watering is due to moderately excessive amount of mineral micropollutants original from industrial wastewaters is evident, judging the WQA class of yellow was verified (see Table 4). This study recommends to the government of the Selangor state including all the stakeholders to envisage as priority the agricultural development and agribusiness in the region if the quantity of inland waters for supporting the needs of multifarious activities is sufficient enough.

Analysis of the water suitability for aquaculture use

Major pollutants of the Selangor River water with emphasis on the alteration of suspended particles control aptitude of the water for aquaculture use (see Table 4). This study finds that the influences of both the alterations of mineral micropollutants and oxidized organic matter are likely to be clearer downstream the station 08. The excessive amounts of suspended particles, organic matter, and mineral micropollutants have declined into a very bad water aptitude which is forbidden to be used for aquaculture use. Experimental data validation shows that the WQA classes are red (see Table 4). A moderate suitability of the water for aquaculture use in the middle river segment (stations 04 and 06) relates to the suspended particles alteration judging the WQA classes are yellow (see Table 4). Still the waters on this river segment are moderately suitable to be used for all the adult fishes which are not very sensitive to pollution (Oudin et al. 1999). The aptitude of the water upstream the station 02 is excellently suitable for aquaculture use judging the WQA classes are blue (see Table 4). Thus the stream water is acceptable to be used for all the fish breeding including eggs and sensitive species.

The fact that three alterations (i.e., suspended particles, oxidized organic matter, and mineral micropollutants) may induce to a very bad water aptitude for aquaculture use. The potential sources of pollutant loads from poultry farms, domestic and industrial wastewaters, and sand mining are expected. To improve the aptitude of the Selangor River water to be acceptable to be allocated for aquaculture use, some amounts of suspended solids, organic matter, and minerals should be removed from their potential sources. Thus the installation of the appropriate WWTP for poultry farms and domestic and industrial wastewater is recommended. Besides, implementing the best practice of the sand mining may reduce suspended particles originally generated from soil erosion of mining activities.

Conclusion

This study used the water quality data to assess the suitability of the Selangor River water for five different uses and its aquatic ecosystem. The analysis of using the WQES classified the stream water quality in well-defined groups. Selangor River emerges from the foothills of Fraser's hill and traverses the northeast region of Selangor state for some 110 km where the major part of the river water was verified is unsuitable for aquatic biota, drinking water production, leisure and aquatic sport, and aquaculture. Deterioration of the water quality is due to the excessive amounts of microorganisms, suspended particles, oxidized organic matter, and mineral micropollutants. The potential pollutants that originate from poultry farms, domestic and industrial wastewater, and sand mining were predictable. The assessment of WQA was conducted as it is described as being a DSS investigation, contributing to water users in allocating their water right in accordance with the available water and its safe quality and to decision makers in managing water resources in the region. The significance of using the WQES may transform large quantities of the water quality data into a single number of the information of WQA and provides a unique performance indicator of the water aptitude.

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